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Abstract

This paper suggests a modelling of the labelling procedure consistent with empirical observations, that allows the endogenous calculation of labelling criteria.

The authority in charge of the labelling program chooses the level of labelling criteria so as to maximise the social surplus, anticipating competition between firms in environmental qualities and prices. While accounting simply for the informational role of labels, this model allows to understand observed behavior such as firms' ignorance of a label, resistance, support or indifference of firms to the labelling program and the decision of the authority not to set up a label.

Keywords: Eco-label, Labelling Criteria, Environmental Quality, Price Competition, Firms' Position.

JEL Classification: C72, L13, Q20.

1 Introduction

An eco-label is defined as a "voluntary trademark that is awarded to products deemed to be less harmful to the environment than other products within the same category" (UNDP(CSD), 1996 [23]). It is a "market based instrument of environmental policy. Its main purpose is to raise consumer awareness about the environmental effects of products, to inform consumers about the environmental characteristics of a product and to promote the adoption of more environmentally sound production methods and technologies" (UNEP, 1997 [24]). All what is expected from eco-labels in terms of information, competition and environment, has been summarized in the previous statement, the three effects thought to be intimately related. But evidence shows that these expected outcomes do not systematically hold. Indeed firms may oppose or be indifferent towards eco-labelling programs whereas they were expected to jump at the opportunity of setting up a label because it allows product differentiation thus relaxes price competition (Nadaï, 1998) [17]. When an eco-label is set up, firms may ignore it, the eco-label resulting in no environmental improvement. Finally, the authority in charge of the label may decide not to set up an eco-label.

The primary purpose of the paper is to suggest a modelling of the labelling procedures consistent with empirical observations. Accounting simply for the informational role of labels, the model allows to explain the position of firms towards the eco-label and characterize conditions under which the eco-label results in environmental improvement. As a by-product, we show how the position of firms towards the eco-label may

be interpreted as a signal to reveal partial information on demand and costs. Finally we endogenize labelling criteria.

A label is needed in the environmental field because the environmental performance of firms is a "credence attribute" which is impossible or too costly for consumers to obtain (OECD, 1997 [19]). Without information on quality "bad money drives out the good" (Akerlof, 1970 [2]). Moreover environmental efforts cannot be revealed through decentralized mechanisms as experience attributes for instance[1]. The intervention of a centralized credible authority is thus needed in order to improve information on environmental efforts and urge firms to compete for the "green segment"[2].

Ibanez and Stenger (2000) [12] prove indeed that the improvement of information on products may be efficient in environmental terms[3]. However they only deal with a better information on products of fixed qualities supposing an exogenous level of labelling criteria. This type of model may account for the situation in the short run, price being the most easily adjustable strategic variable. But there is no reason to suppose that firms do not change their environmental qualities in the mid and long run, eco-labels being precisely designed to urge their efforts in this respect. Moreover firms participate in the stage of determination of labelling criteria. It would thus be natural to suppose that they defend their interests taking into account their anticipation of competitional stages. This is precisely the idea captured in this paper suggesting a way to endogenize labelling criteria that links the position of firms towards the label, the value of labelling criteria, competition between firms at the following stages and environmental efforts of firms.

We use a vertical differentiation model with a central authority and two identical firms, that models the labelling procedure, accounting simply for the informational role of labels. Amacher, Koskela and Ollikainen (2004) model the environmental efforts of firms through a three stage game of investment, environmental quality provision and price competition, also in a vertical differentiation framework. But they tackle neither the information issue on environmental quality nor the endogenization of criteria.

For fixed labelling criteria, the description of competition between firms allows to understand the position of firms towards the label. When the costs of conforming

[1]See for instance Grossman (1981) [10] and Shapiro (1983) [21].

[2]See Cason and Gangadharan (2002) [5] for a foundation through a laboratory experiment.

[3]See Bjorner et al. (2004) [4] for empirical evidence on the effect of eco-labelling on consumers' choice.

to the label are too high or too low, the market cannot bear the existence of both firms, which results in either firms' resistance or indifference towards the label. When these costs are too high, setting up a label leads to no change in terms of environmental improvement and competition (because no firm will apply for it) thus meets indifference from firms. More surprisingly, *when these costs are too low*, a non-labelled firm unable to stand competition with a labelled one, must leave the market, which results in a firm's resistance. When this occurs for all labelling criteria, the firm resists to the eco-labelling program itself and not only to a range of values of labelling criteria. Hence a partial resistance (from some firm) would mean that conforming to the label involves too low costs and that setting up an eco-label would result in the labelling of all the products available on the market!

To endogenize the labelling criteria, we suppose that an authority maximizes a total surplus anticipating competition between firms in environmental qualities and prices. With specific cost functions, we calculate the optimal labelling criteria and prove in particular that it may be optimal to choose not to set up an eco-label for different reasons. It may be either because no change is expected from setting up an eco-label whatever the criteria, the resistance cost is too high, or the negative effects on consumers' surplus stemming from the rise of prices allowed by eco-labelling, outweigh the positive ones.

The paper is organized as follows. Section 2 describes the model. Section 3 deals with firms' choices for some given value of labelling criteria. In Section 4 labelling criteria are calculated. Section 5 concludes.

2 The model

In a given industry, we consider a measurable environmental characteristic, for which there exists a consensus on the environment friendly production methods[4]. For instance fertilizers and pesticides use or the throwing out of pollutants in the air or in the water are unanimously considered as harmful for the environment. Eco-labelling being based on Life Cycle Assessment (LCA) or on Main Environmental Impacts of products, the so-called "environmental quality" would be some composite characteristic expected to objectively and synthetically measure the attention attached by the firm to the

[4]We thus ignore the possibility of divergence of opinions about the environmentally sound methods as was for example the case with paper products within the European Union in 1993.

environment: choice of raw materials, technologies, packaging material, etc.

We suppose that consumers are aware of the need of preserving the environment for current and future generations. This consciousness is tackled through their preference for the most environment friendly product if they have the choice between several "environmental qualities" *sold at the same price*. Thus a vertical differentiation model seems to fit this type of situation. To focus on eco-labelling, products are supposed to differ only by their environmental qualities.

We consider two firms $i = 1, 2$. As Mussa and Rosen (1978) [15], we suppose that indirect utility of a consumer of type θ buying from Firm i a unit of good of quality q_i at price p_i, is given by:

$$V_i(\theta) = \theta q_i - p_i.$$

$\theta \in [\underline{\theta}, \overline{\theta}]$ with $\underline{\theta} > 0$, measures the intensity of preference of the consumer for quality. The more θ is large the more the consumer attaches importance to the environment, and consequently the more she is willing to pay in order to acquire a better quality. For a better understanding, consider a consumer θ who has the possibility of buying one of two products $q_1 < q_2$ sold at prices p_1 and p_2. The purchase of the best quality procures to her a better utility as long as $p_2 \leq \theta(q_2 - q_1) + p_1$. The difference $\theta(q_2 - q_1)$ may be interpreted as the willingness to pay of Consumer θ to acquire a better quality, called "the green premium account". $\underline{\theta} > 0$ implies that all consumers are willing to pay larger prices to acquire better qualities[5].

Consumers are supposed to be uniformly distributed on the segment $[\underline{\theta}, \overline{\theta}]$ with a density equal to 1. Each consumer is supposed to buy one unit of good from the firm that ensures to her the best utility. When both firms choose the same qualities and prices, they are supposed to share equally the market.

The segment $[\underline{q}, \bar{q}]$ is the quality strategy space and $[0, y]$ is the price strategy space, y being the income, the same for all consumers, supposed to be sufficiently high so as it is never constraining.

The environmental quality being difficult to observe by a simple consumer, the setting up of an eco-label aims at providing consumers with partial information. The attribution of an eco-label to a firm means for consumers that the environmental quality of the firm of quality q exceeds some given threshold $\tilde{q}$, called in all the following "labelling

[5]For an empirical measure of the willingness to pay for green products see for instance Roe et al. (2001) [20] and Bjorner et al. (2004) [4].

criteria", and supposed to be perfectly known by all parties (consumers, firms and the authority).

Hence for a consumer, a labelled firm has *a priori* a quality $q \geq \tilde{q}$ and a non-labelled one has a quality $q < \tilde{q}$. The simplest beliefs that consumers may have about the firms' qualities satisfying these inequalities is to suppose that an eco-labelled product matches exactly the value of that threshold $q = \tilde{q}$ and that a non-labelled product has the minimal environmental quality $q = \underline{q}$.

Production of some quality q is characterized by a constant marginal cost (w.r.t. quantity):

$$c(q),$$

c being an increasing function with quality q (because environment friendly processes are supposed to be more costly).

Once the eco-label is fixed, the preceding hypotheses imply that it is never profitable for firms to produce a quality different from $\underline{q}$ and $\tilde{q}$. The choices of firms are thus consistent with the beliefs of consumers. Indeed as consumers are not able to make the difference between $\underline{q}$ and a quality q satisfying $\underline{q} \leq q < \tilde{q}$, and between $\tilde{q}$ and a better quality, producers try to set the product in "some category" (labelled or not labelled) at the least cost, rather than in the segment of all possible qualities[6]. Tackling the information on environmental quality in this way results simply in replacing the segment of *a priori* possible qualities by a pair of relevant qualities.[7]

When a label is set up, each firm must decide either to keep its quality or to move to quality $\tilde{q}$, which involves a fixed cost (w.r.t. quantity) increasing with the difference between the initial and the new quality:

$$I(\tilde{q} - \underline{q}),$$

with $I(0) = 0$ (which means that no investment is needed if the firm decides to keep its initial quality). The more usual hypothesis of a fixed cost independent of quality

[6]For an illustration, the next example is derived from food industry: ' ... if the requirement for making a "low fat" claim is that total fat per serving is less than or equal to 3 grams [ ], then companies are likely to focus on getting below these levels rather than on taking fat to the lowest practicable level..." (OECD, 1997 [19])

[7]Amacher, Koskela and Ollikainen (2004) ignore the information aspect of the problem. Indeed as they consider that firms can choose their qualities among all possible ones, consumers are thus supposed to be perfectly informed on each firm's quality. Moreover there is no threshold of quality required to get the label.

is a particular case of our more general one.[8] Note that $c(q)$ is a unit cost associated to a given level q of environmental quality, which may correspond for instance to the energy costs or the use of chemicals more or less harmful to the environment; while $I(\tilde{q} - \underline{q})$ is a fixed cost independent of the produced quantity, that may correspond for instance to the expenditure necessary to acquire some new equipment to process the thrown water.

Eco-labelling programs generally include three stages. The first stage is devoted to the determination of the general framework concerning the label. Specifically the product group for which an eco-label may be set up is determined and a market study is engaged. Before engaging in an eco-labelling program, the authority checks two conditions: the existence of an ecological consumers' awareness and the willingness of consumers to pay for the environmental improvement. The use of this model ensures that both conditions be satisfied.

In the second stage the labelling criteria which are the minimal environmental efforts required to get the label are fixed. In the two first stages, several actors are involved: consumers' organizations, trade unions, ecological associations and firms or their representative associations. In the third stage, each firm may or not apply for the eco-label, once the eco-label and criteria set up. The certifying authority examines the conformity of the firms applying for the label with the labelling criteria and decides accordingly whether or not to award the label.

Supposing that the first step has been taken, we suggest the following model of the two last stages that tackles the role of firms.

1. An authority chooses and announces the labelling criteria $\tilde{q}$.

2. Firm 1 chooses its quality q_1.

3. Firm 2 chooses its own quality q_2.

4. Finally they simultaneously choose prices in $[c(q_i), y]$, $i = 1, 2$.

At each step firms observe the result of the preceding one (if there is any) before

[8] Here is another difference with Amacher et al.. While they dissociate investment decisions from quality choice, we suppose that both decisions are linked.

making their choice[9]. Consumers are supposed to perfectly observe the level of labelling criteria $\tilde{q}$ and to observe whether firms are labelled or not before making their choice.

In some cases a firm may have the choice between two actions giving it the same profit. We then suppose the following hypothesis.

$\mathcal{PA}$ (Preference for Activity) At the same level of profit, the firm prefers the situation in which it is more active (has a larger demand).

To model simply the choice of the labelling criteria, we suppose that the authority maximizes a collective surplus which depends on consumers' surplus, the profits of firms, a damage function depending on the consumed quality and, when a firm must leave the market, a cost which may be interpreted as a resistance cost[10].

We suppose that each produced and consumed unit involves a damage D, which is decreasing with the quality at a constant rate μ:

$$\frac{\partial D}{\partial q} = -\mu.$$

μ reflects someway the authority's concern for the environmental effects, present and future ones, which are not heeded by consumers. When $\mu = 0$, the authority takes into account only the interest of the "present generation" for the environment.

When a firm must leave the market, we suppose that this involves a fixed social cost C_R. Indeed it is never a trivial matter when a firm is compelled to shut down. At least temporarily, the involved employees are laid off, consumers suffer from a disruption in supplies of the produced good, etc.

To calculate precisely the labelling criteria (Section 4), we take the following particular cost functions:

$$c(q) = \alpha q$$

[9]We suppose sequentiality in quality choice only to avoid multiplicity of equilibria. In this particular finite subgame in qualities where the strategy spaces are reduced to a pair, this does not modify at all the choice of firms at equilibrium thus does not influence the endogenous calculation of criteria, but allows the selection of an equilibrium when there is more than one thus the "identification" of firms. As may be seen in the different proofs, sequentiality allows Firm 1, the Stackelberg leader in quality choice, to choose the most comfortable equilibrium when there is more than one. When for instance the market does not bear the existence of both firms, sequentiality allows to identify the firm to leave. All our results hold when quality choices are simultaneous but the exposition would be less clear.

[10]We neglect the cost of the labelling program.

and

$$I(\tilde{q} - \underline{q}) = \beta(\tilde{q} - \underline{q})^2$$

We suppose that the authority maximizes the sum of profits and consumers' surplus, minus the damage function and the resistance cost in case one firm leaves the market.

In all the following, when appropriate we denote by $\delta = \tilde{q} - \underline{q}$.

3 Firms' choices for fixed labelling criteria

In this section, the game is solved for a fixed value of labelling criteria. By backward induction, we start with the final step corresponding to the choice of prices, then we deal with the quality choice.

When no eco-label is set up both firms are active sharing the market, producing $\underline{q}$ and making no profit.

Suppose now that an eco-label is set up with the labelling criteria $\tilde{q}$. If firms choose the same quality, price competition is a competition "à la Bertrand"; firms make no profit when they both produce $\underline{q}$. When they both produce $\tilde{q}$ they make a negative profit equal to $-I(\tilde{q} - \underline{q})$. In both cases they are active sharing equally the market.

Standard calculations provide the price equilibrium in the competition between a labelled firm and a non-labelled one. It depends on the way the marginal cost $c(q)$ increases between the qualities $\underline{q}$ and $\tilde{q}$. Accordingly, three cases have to be distinguished: high, low and "balanced" variable costs.

Regarding the position of firms towards the eco-label, a firm supports the eco-label if it is better off at the resulting equilibrium relative to the situation without eco-label. It resists to the eco-label if it is worse off. A firm is indifferent towards the eco-label if both situations amount to the same for the firm in terms of profit and activity. Hence when a firm makes a positive profit at quality equilibrium, it supports the eco-label. It resists to the eco-label if it makes a negative profit at quality equilibrium or makes no profit but is less active.

Next we provide the results relative to quality choice in the three cases, then deduce the possible outcomes in terms of firms' position and environmental improvement. Calculations and the results' proofs are provided in Appendix A.

Result 1 (High variable costs) *Suppose an eco-label is set up with criteria satisfy-*

ing

$$\frac{c(\tilde{q}) - c(\underline{q})}{\tilde{q} - \underline{q}} > 2\overline{\theta} - \underline{\theta}. \tag{1}$$

At quality equilibrium, no firm gets the label. They both are active producing $\underline{q}$ and making no profit. Both firms are indifferent towards such criteria. Setting up such an eco-label results in no environmental improvement.

Result 1 describes the situation where no labelled product is viable because of variable costs. This is so when the variable cost increases too quickly between $\underline{q}$ and $\tilde{q}$. We deduce from Result 1 conditions under which a labelled firm is *never* viable because of variable costs.

Corollary 1 *Suppose*

$\mathcal{H}$ **1** *$c'(q) > 2\bar{\theta} - \underline{\theta}$ for all $q \in [\underline{q}, \overline{q}]$.*

Then for each value $\tilde{q} \in [\underline{q}, \overline{q}]$, no firm gets the label and both firms produce $\underline{q}$. Firms are indifferent towards the eco-label program. Setting up an eco-label never results in environmental improvement.

When $\mathcal{H}1$ holds, whatever the labelling criteria, the increasingness of production cost with quality is too strong to allow to a labelled firm to survive, even if the investment required to move to a better quality is ignored. We now deal with the case of too low variable costs.

Result 2 (Low variable costs) *Suppose an eco-label is set up with criteria $\tilde{q}$ satisfying*[11]*:*

$$\frac{c(\tilde{q}) - c(\underline{q})}{\tilde{q} - \underline{q}} < 2\underline{\theta} - \overline{\theta}. \tag{2}$$

At price equilibrium in the competition between a labelled firm and a non-labelled one, only the labelled firm is active and equilibrium prices are given by:

$$\begin{cases} \underline{p} = c(\underline{q}) \\ \tilde{p} = c(\underline{q}) + \underline{\theta}\delta. \end{cases} \tag{3}$$

Regarding qualities' choice,

[11] When $\overline{\theta} > 2\underline{\theta}$ (of which a particular case is $\underline{\theta} = 0$), Inequation 2 never holds. There is always room for a non-labelled firm when there exist consumers indifferent to quality or when the market is sufficiently large.

1. *If the profit of the labelled firm at equilibrium prices (given by (3)) is non-negative, the unique quality equilibrium involves Firm 1 producing $\tilde{q}$ and Firm 2 proposing $\underline{q}$ but with no demand. Only labelled products of improved quality survive.*

   Firm 1 supports the label while Firm 2 is against it.

2. *If the profit of the labelled firm at the equilibrium prices (given by (3)) is negative, then the unique equilibrium in qualities once an eco-label is set up, involves both firms producing $\underline{q}$ thus no firm gets the label. Setting up an eco-label results in no environmental improvement. Both firms are indifferent towards the eco-label.*

Result 2 describes the situation where only the labelled firm is viable when it competes with a non-labelled one. This occurs when the variable cost increases too slowly between $\underline{q}$ and $\tilde{q}$. Production of a good quality is not sufficiently costly to constrain the labelled firm to sufficiently high prices, condemning the non-labelled firm to inactivity. But the profitability of a labelled one depends on the investment to be made to adopt the label, which gives the two enumerated subcases.

In the first subcase, the investment required to get the label is not too high, at equilibrium, one firm gets the label while the second one keeps its quality. The non-labelled firm has the same profit as in the situation before labelling but has no demand, thus (using $\mathcal{PA}$) is worse off after setting up the label. A resistance is thus expected from firms when the costs of labelling, variable and fixed ones, are low! And it is precisely in this case that all products available on the market will be labelled after setting up an eco-label.

Sequentiality of quality choice is needed here. Indeed if the game were simultaneous, since there are two equilibria where one firm or the other leaves the market, there would be some indetermination on the firm that will actually leave the market. Sequentiality implies that Firm 2, the follower, will leave the market thus feels concerned about this issue in the negotiation step. The resistance to the label is clearly and simply tackled this way. The second subcase corresponds to a too high investment to get the label. Even if the variable cost of conforming to the label allows the activity of a labelled firm once it gets the label, no firm finds profitable to do so after considering the investment required to get the label.

The profit of a labelled firm may always remain positive or always remain negative, for all possible criteria. This is the object of Corollary 2.

Corollary 2 *Suppose c and I are convex. Suppose also that c satisfies*

$\mathcal{H}$ **2** $\bar{\theta} < 2\underline{\theta}$ *and* $c'(q) < 2\underline{\theta} - \bar{\theta}$ *for all* $q \in [\underline{q}, \overline{q}]$.

1. *If* $[c(\underline{q}) - c(\overline{q}) + \underline{\theta}(\overline{q} - \underline{q})](\overline{\theta} - \underline{\theta}) - I(\overline{q} - \underline{q}) > 0$, *then for all* $\tilde{q} \in [\underline{q}, \overline{q}]$, *setting up an eco-label with criteria* $\tilde{q}$ *results in the activity of only one firm, a labelled one. There is never room for two firms. Resistance from one firm is expected against all possible values of criteria thus against the labelling program itself.*

2. *If* $(\underline{\theta} - c'(\underline{q}))(\bar{\theta} - \underline{\theta}) - I'(0) \leq 0$. *Then for all* $\tilde{q} \in [\underline{q}, \overline{q}]$ *at equilibrium both firms continue to produce a non-labelled product of quality* $\underline{q}$. *Indifference towards the eco-label is expected for all possible values of criteria thus towards the labelling program.*

Corollary 2 describes the case where, whatever the labelling criteria, only the labelled firm is viable at price equilibrium, if ever the investment is ignored. Once the investment to get the label engaged by one firm, whatever the criteria, a non-labelled firm can never stand competition with the labelled one. Considering the qualities' choice, the equilibrium involves a labelled firm only if the investment is not too high.

We finally examine the case of intermediary variable costs.

Result 3 (Balanced variable costs) *Suppose an eco-label is set up with criteria* $\tilde{q}$ *satisfying:*

$$2\underline{\theta} - \bar{\theta} < \frac{c(\tilde{q}) - c(\underline{q})}{\tilde{q} - \underline{q}} < 2\bar{\theta} - \underline{\theta} \tag{4}$$

Two cases have to be distinguished:

1. *If*

$$\tilde{\pi} = \frac{(\tilde{q} - \underline{q})}{9}\{2\bar{\theta} - \underline{\theta} - \frac{c(\tilde{q}) - c(\underline{q})}{\tilde{q} - \underline{q}}\}^2 - I(\tilde{q} - \underline{q}) \geq 0, \tag{5}$$

then at the unique perfect equilibrium, firms respectively produce $\underline{q}$ *and* $\tilde{q}$ *(Firm 1 choosing among the two qualities the one that ensures to it the best profit) and charge the prices given by:*

$$\begin{cases} \underline{p} = (1/3)[2c(\underline{q}) + c(\tilde{q}) + (\overline{\theta} - 2\underline{\theta})(\tilde{q} - \underline{q})] \\ \tilde{p} = (1/3)[c(\underline{q}) + 2c(\tilde{q}) + (2\overline{\theta} - \underline{\theta})(\tilde{q} - \underline{q})] \end{cases} \tag{6}$$

The market is shared between a labelled and a non-labelled firm, each having a positive demand and a positive profit thus supporting the eco-label.

2. *If*

$$\tilde{\pi} = \frac{(\tilde{q} - \underline{q})}{9}\{2\bar{\theta} - \underline{\theta} - \frac{c(\tilde{q}) - c(\underline{q})}{\tilde{q} - \underline{q}}\}^2 - I(\tilde{q} - \underline{q}) < 0, \tag{7}$$

then at the unique quality equilibrium both firms sell $\underline{q}$. Hence both are indifferent towards the eco-label.

Result 3 describes the situation where a labelled firm and a non-labelled one are viable at price competition *once one firm has decided to get the label.* This is the case when the increasingness of the variable cost between the initial quality $\underline{q}$ and the quality required to get the label, $\tilde{q}$, is "balanced". It is neither too slow nor too quick, which allows the viability of both types of firms at price equilibrium. But at the subgame perfect equilibrium, the decision to get or not the label depends on the investment required to do so.

The first subcase describes the situation with sufficiently low investment. It corresponds to the situation profitable to both firms. With such an eco-label, both firms are better off with the eco-label, eco-labelling softens price competition and allows better profits to both firms relative to the situation without eco-label. A strong support from both firms is thus expected in this case. In the second subcase the investment to be made to get the label is too high. Thus no firm finds profitable to get the label.

Note that the same outcome may be observed in the different cases and that generally (or generically), as $\tilde{q}$ describes all the interval of possible values $[\underline{q}, \overline{q}]$, the situation should be alternately described by the different results. However the situation may be "locked" in only one type of situation as in Corollaries 1 and 2.

From the preceding analysis, three outcomes may be observed regarding environmental improvement and position of firms.

Indifference to the label and no environmental improvement. After setting up an eco-label no change is observed: both firms continue to produce the same quality

and no firm gets the label. This outcome has been observed with the european eco-label for five categories (for instance Hard floor coverings and Washing Machines), the Blue Angel for ten products and the White Swan for five products (www.svanen.nv/Eng), for which eco-labels exist but no firm has applied for them. This outcome does not result in our model from any collective or cooperative action against the label (what may be called "boycott" of the eco-label). It results from a pure non-cooperative behavior.

This may stem either from high variable costs (Result 1) or high investment costs (Second case of Result 2 and second case of Result 3). When the structure of variable costs is the cause, it is a particular case of the finiteness property well-known in vertical differentiation models[12]. But the phenomenon is different when the non-viability of the labelled firm stems from the investment required to move to a better quality.

High variable costs may be caused for instance by the requirement of the eco-label of manual work at some stage of production, the use of expensive packaging material less harmful for the environment, or a too strict water process. As for the case of high investment costs, consider for example the labelling of electricity production and the initial case where both firms produce with nuclear technology. Suppose that the label does not allow this technology. To be labelled a firm must invest heavily in other technologies (for instance dams to produce with hydraulic power). Even if the variable cost is low, the investment to be made may be so high that both firms do not apply for the label.

When this outcome is expected for all possible values of labelling criteria (Corollary 1 and Second case of Corollary 2), then it should be preceded by indifference towards the labelling program itself. The massive absence of firms from negotiations may reveal this indifference. Then the authority should give up with the labelling program because no change is expected after setting up an eco-label, in environmental as well as competitional terms.

Resistance and complete environmental improvement. When labelling involves too low costs, variable and fixed ones, setting up an eco-label results in the activity of only one firm, a labelled one. Thus non-labelled products disappear from the market (First case of Result 2). This outcome should lead to an opposition of the firm having to leave. Paradoxically, resistance during negotiations should be followed by the labelling of all products thus a total environmental improvement. When this outcome is expected

[12]In this respect see for example Lahmandi-Ayed, 2000.

for all possible values of labelling criteria (First case of Corollary 2), the resistance is against the program itself and not only against a range of labelling criteria. Resistance to an eco-label may be so strong that it blocks the program. This has been observed in several labelling programs. For instance according to Nadaï (1997), two years after the beginning of negotiations in 1993 to set up a european eco-label (Small Flower) for batteries, no eco-label had been set up because of the strong resistance of firms.

The total improvement of products qualities may relate to the 'race to labelling' observed for instance in the case of paper for notebooks in Denmark and Sweden where 80 % of the products available on the market are labelled. However the observed phenomenon may be much more complex and may stem from different factors *not taken into account in our simple model*, such as psychological and informational factors. In our model even if *consumers are supposed to be perfectly informed on the level of criteria and to have preferences and a distribution not influenced by the eco-label*, the model allows the emergence of a situation where all products available on the market are labelled.

Strong support of firms and partial environmental improvement. When the variable costs of quality are neither too low nor too high and the investment required to get the label is sufficiently low, setting up an eco-label results in the activity of both firms with better profits than the situation without eco-label. Strong support of both firms is thus expected. Both labelled and non-labelled products co-exist on the market. Setting up an eco-label thus results in partial environmental improvement.

It is likely that authorities have in mind this type of situation while promoting an eco-label[13]. However under some conditions on costs and demand (the situations examined in Corollaries 1 and 2), this situation is possible with no labelling criteria. Moreover this situation may not be the optimal one. We will return to this issue later.

The european "Small Flower" eco-label (set up in 1992) for indoor paints and varnishes (OJEC, January 6, 96 and January 9, 1999) and The FSC (Forest Stewardschip Council set up in 1993) illustrate such a scenario, for which the labelled and non-labelled products co-exist on the market.

As a by-product of this analysis, the position of firms in negotiations is a signal

[13]About the french eco-label "NF-environnement": "The levels concerning the main requirements [ ] have been conventionally fixed in order to reach the percentage 10 % of products deserving the label NF-environnement" AFNOR (1993).

that may reveal partial information in terms of cost and demand conditions and the expected outcome after setting up an eco-label. The authority may meet three cases. First indifference of firms prior to the setting up of the eco-label would reveal too high costs of labelling, either variable or fixed ones and would mean that firms would ignore the label, eco-labelling resulting in no change. Second resistance to the label would reveal too low variable and fixed costs and would mean that a total improvement of environmental quality should follow the setting up of a label. Finally strong support of firms would reveal balanced variable costs and low fixed ones and would mean that a partial improvement of environmental quality should stem from setting up an eco-label.

Suppose finally the general case of n firms. At the qualitative level we should obtain similar results. Since firms producing the same quality are compelled to price at marginal costs, there may not be more than a single eco-labelled firm. At quality equilibirum, three outcomes are possible. When variable or fixed costs are too high all firms keep their qualities. When variable and fixed costs are low only the labelled firm survives while the others shut down. Finally when variable costs are balanced and fixed costs are low, the market is shared between one eco-labelled firm and $n-1$ non labelled firms each having a positive demand but only the labelled firm making profit. The observed outcomes are thus qualitatively the same as the duopoly case. However we think that the results obtained with price competition are too extreme as soon as more than two firms are considered, since at most one firm may be eco-labelled whatever the number of competing firms. We think that in this case quantity competition (instead of price competition) should better describe competition between firms.

4 Endogenizing labelling criteria

In this section, we calculate endogenously the labelling criteria considering particular cost functions:

$$c(q) = \alpha q$$

$$I(\tilde{q} - \underline{q}) = \beta(\tilde{q} - \underline{q})^2$$

As we already mentioned in the model description, the authority maximizes the social welfare equal to the sum of profits and consumers' surplus minus the damage

and the resistance cost in case one firm leaves the market[14]. To make its decision, the authority must anticipate the competition stages for each possible value of labelling criteria.

For exposition clarity, we keep the same analysis order. The results of the preceding section are applied to calculate quality equilibrium in different cases. As function $c'(q)$ is constant w.r.t. quality q, we have always $c'(q) > 2\overline{\theta} - \underline{\theta}$ (application case of Result 1 and Corollary 1), always $c'(q) < 2\underline{\theta} - \overline{\theta}$ (application case of Result 2 and Corollary 2), or always $2\underline{\theta} - \overline{\theta} < c'(q) < 2\overline{\theta} - \underline{\theta}$ (application case of Result 3). These cases are dealt with in the three following subsections. Proofs are given in Appendix B.

4.1 Too high variable costs

When $\alpha > 2\overline{\theta} - \underline{\theta}$ Corollary 1 applies. Setting up an eco-label results in no change at all, whatever the labelling criteria. Thus the authority should give up with the labelling program.

4.2 Too low variable costs

Suppose now $\alpha < 2\underline{\theta} - \overline{\theta}$. Then Corollary 2 applies. If an eco-label is set up, a non-labelled firm is never viable, which results in a resistance cost.

Suppose an eco-label is set up with $\tilde{q} > \underline{q}$. When a labelled firm and a non-labelled one compete, the price equilibrium is provided in Result 2 and the profit of the labelled firm is given by:

$$\tilde{\pi} = (\underline{\theta} - \alpha)(\overline{\theta} - \underline{\theta})(\tilde{q} - \underline{q}) - \beta(\tilde{q} - \underline{q})^2.$$

$\tilde{\pi} \geq 0$ is equivalent to

$$\delta = \tilde{q} - \underline{q} \leq \overline{\delta} = \frac{(\underline{\theta} - \alpha)(\overline{\theta} - \underline{\theta})}{\beta}.$$

(Note that $\overline{\delta} > 0$ when $\alpha < 2\underline{\theta} - \overline{\theta}$.)

Note that $\tilde{q}$ corresponding to $\delta = 0$ (i.e. $\tilde{q} = \underline{q}$) is strictly equivalent to the situation without eco-label. Applying Result 2, labelling criteria corresponding to $\tilde{\pi} < 0$, i.e. $\delta > \overline{\delta}$, do modify nothing in terms of competition and environment relative to the situation without eco-label, thus amount to set up no eco-label. Hence to examine all the relevant cases, it is sufficient to deal with labelling criteria satisfying

[14] Plausible arguments exist for alternative objective functions (Heyes and Maxwell, 2004).

$$\delta(=\tilde{q}-\underline{q}) \in [0, \overline{\delta} = \frac{(\underline{\theta}-\alpha)(\overline{\theta}-\underline{\theta})}{\beta}].$$

Although the authority is theoretically free to choose the labelling criteria in all the quality segment, its choice is in fact constrained by competitional stakes to have an effect thus to make sense. Choosing "too severe" labelling criteria ($\delta > \overline{\delta}$) has no effect at all. The following result and corollary provide the optimal value of δ.

Result 4 *Denote by*

$$f(\delta) = (\underline{\theta}-\alpha)(\overline{\theta}-\underline{\theta})\delta - \beta\delta^2 + \frac{(\overline{\theta}-\underline{\theta})^2}{2}\delta + \mu\delta(\overline{\theta}-\underline{\theta}).$$

The optimal value δ^* is given below.

1. *When $\mu > \frac{\overline{\theta}-\underline{\theta}}{2}$,*
   - *If $\alpha \geq \alpha^*$,*
     - *if $C_R < f(\overline{\delta})$ then $\delta^* = \overline{\delta}$.*
     - *if $C_R > f(\overline{\delta})$ then $\delta^* = 0$.*
   - *If $\alpha < \alpha^*$,*
     - *if $C_R < f(\tilde{\delta})$ then $\delta^* = \tilde{\delta}$.*
     - *if $C_R > f(\tilde{\delta})$ then $\delta^* = 0$.*
2. *When $\mu < \frac{\overline{\theta}-\underline{\theta}}{2}$, then*
   - *if $C_R < f(\tilde{\delta})$ then $\delta^* = \tilde{\delta}$.*
   - *if $C_R > f(\tilde{\delta})$ then $\delta^* = 0$.*

Interestingly, we can deduce the optimal value of labelling criteria when the resistance cost is close to zero.

Corollary 3 *Consider the case where the resistance cost is close to zero. The optimal value of labelling criteria δ^* is given by the following.*

1. *When $\mu > \frac{\overline{\theta}-\underline{\theta}}{2}$,*

- *If* $\alpha \geq \alpha^*$ *then* $\delta^* = \overline{\delta}$.
- *If* $\alpha < \alpha^*$ *then* $\delta^* = \tilde{\delta}$.

2. *When* $\mu < \frac{\overline{\theta}-\underline{\theta}}{2}$, $\delta^* = \tilde{\delta}$.

The optimal value of labelling criteria depends on three parameters: production cost, the damage parameter and the resistance cost. Increasing labelling criteria in the authorized segment has countervailing effects. It improves totally the environmental quality, which has a positive effect on the environment and consumers' surplus. It allows higher prices having a positive effect on the firm's profit but negative ones on consumers' surplus. Finally it increases the production cost having negative effects on the firm's profit.

Ignoring the resistance cost, as the production cost is low in this case, the total effect is positive, i.e. it is always better to set up a label. But the optimal level of criteria depends on the weight of each effect. For low values of the damage parameter (μ), it is optimal to set up moderated criteria. The environmental effect is not strong enough to justify too severe criteria. For high values of μ, the optimal value of criteria depends on the cost parameter. For high costs (high α), it is optimal to set up criteria as severe as possible. Indeed increasing α allows high prices of the labelled product, which has positive effects on the firm's profit, apparently not mitigated by the negative effects on costs and consumers' satisfaction.

Considering the resistance cost, before setting up a label, the authority must appraise the social cost resulting from the departure of a firm and compare this loss with the social benefit stemming from the eco-label in the best case, i.e. with the best level of criteria possible. Hence in the case of low variable costs, the only reason that may prevent the authority from setting up an eco-label, is thus of political or social nature.

4.3 Balanced variable costs

When $2\underline{\theta} - \overline{\theta} < \alpha < 2\overline{\theta} - \underline{\theta}$, Result 3 applies. We carry out an analysis similar to the preceding case. To examine all the relevant cases, it is sufficient to deal with labelling criteria satisfying

$$\delta(= \tilde{q} - \underline{q}) \in [0, \overline{\delta} = \frac{(2\overline{\theta} - \underline{\theta} - \alpha)^2}{9\beta}].$$

Denote by

$$\overline{\alpha} = \frac{4\overline{\theta} + \underline{\theta} + 6\mu}{5}$$

and

$$\underline{\alpha} = 5\underline{\theta} - 4\overline{\theta} + 6\mu$$

two particular values of α. Denote also by

$$\tilde{\delta} = \frac{(2\overline{\theta} - \underline{\theta} - \alpha)(4\overline{\theta} + \underline{\theta} - 5\alpha + 6\mu)}{36\beta}$$

the result of the first order condition. We directly state the result providing the optimal labelling criteria.

Result 5 *Denote by δ^* the optimal value of labelling criteria.*

- *When $\mu > \overline{\theta} - \underline{\theta}$,*

$$\delta^* = \overline{\delta}.$$

- *When $\frac{\overline{\theta}-\underline{\theta}}{2} < \mu < \overline{\theta} - \underline{\theta}$, we have $2\underline{\theta} - \overline{\theta} < \underline{\alpha} < \overline{\alpha} < 2\overline{\theta} - \underline{\theta}$ and the following cases:*

  - *If $2\underline{\theta} - \overline{\theta} < \alpha < \underline{\alpha}$,*

$$\delta^* = \overline{\delta}.$$

  - *If $\underline{\alpha} < \alpha < \overline{\alpha}$,*

$$\delta^* = \tilde{\delta}$$

  - *If $\overline{\alpha} < \alpha < 2\overline{\theta} - \underline{\theta}$,*

$$\delta^* = 0$$

- *When $\mu < \frac{\overline{\theta}-\underline{\theta}}{2}$, we have $\underline{\alpha} < 2\underline{\theta} - \overline{\theta}$, which yields the following:*

  - *If $2\underline{\theta} - \overline{\theta} < \alpha < \overline{\alpha}$,*

$$\delta^* = \tilde{\delta}$$

  - *If $\overline{\alpha} < \alpha < 2\overline{\theta} - \underline{\theta}$,*

$$\delta^* = 0$$

As in the preceding case, increasing labelling criteria in the authorized segment ($[0, \overline{\delta}]$) has countervailing effects. First it improves partially the environmental quality produced, which has a positive effect on consumers' satisfaction and the environment. Second it increases the quality cost, which has a negative effect on firms' profits. Finally, it softens price competition, which has a positive effect on firms' profits but a negative one on consumers' surplus because it increases prices. The optimal value of the criteria depends on the weight of each effect, which in turn depends on the values of the cost parameter and the damage parameter.

For high enough values of the damage parameter μ, it is always optimal to set up a label with criteria as severe as possible. The environmental effect always outweighs all the other effects, independently of the cost. For low values of the damage, the optimal value of labelling criteria depends on the cost. In this case differently from the case of low costs, it is not always optimal to set up an eco-label. For sufficiently high values of α, the cost parameter, it is optimal not to set up a label. In this case the negative effects of increasing labelling criteria (quality cost and higher prices for consumers) outweigh the positive ones in terms of environmental improvement and improvement of firms' profits.

5 Concluding remarks

The formal analysis carried out in this paper provides a simple model of a labelling program that may explain some empirical observations and allows to endogenize labelling criteria. Interestingly, the position of firms being explained, it may be used to foresee the consequences of the setting up of an eco-label in competitional and environmental terms. The calculation and interpretation of the optimal level of criteria turns out to be rather complex although we used a simple model and did not consider sophisticated phenomena related to advertising and psychlogical factors.

Beyond the precise expression of labelling criteria, we interestingly prove that the authority may rationally choose not to set up a label, either because no criteria result in a change, the resistance cost is too high or because negative effects on consumers' surplus stemming from the prices rise allowed by labelling, outweigh the positive ones. This type of decision has been observed in several cases. In 1993 the european commission decided to give up with eco-labels for cat litters and ceramic floors and, according to Nadaï (1997), two years after the beginning of negotiations in 1993 to set up a eu-

ropean eco-label (Small Flower) for batteries, no eco-label had been set up because of the strong resistance of firms.

The conclusion that labelling is not always synonymous of environmental improvement, is shared with other papers considering other issues on labelling. Mattoo and Singh (1994) [14] prove that eco-labelling may lead in some cases to perverse environmental effects because the resulting differentiation may increase the sales of non-labelled products. Due to a "quantity effect" labelling may be harmful to the environment. Dosi and Moretto (2001) [6] prove that if eco-labelling entails a positive image for the firm including for its non ecological products, labelling may increase the polluting capital. With our model we prove that labelling may not improve environmental conditions whereas those aspects are ignored since the total quantity is fixed and no effect in terms of image is considered.

Finally, even if we had in mind ecological labelling and drew almost all the examples from this setting, our analysis and results may apply to any credence attribute if the setting up of a quality label is submitted to the same rules.

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Appendix A

Calculation of the best replies of a labelled and a non-labelled firm in prices

Suppose that firms sell $\underline{q}$ and $\tilde{q}$ respectively at $\underline{p}$ and $\tilde{p}$ and consider price competition. The firm producing $\underline{q}$ is the non-labelled firm or Firm NL and the one producing $\tilde{q}$ is the labelled firm or Firm L.

We need first to compute the best responses in terms of prices. In these conditions the investment made is considered as a sunk cost and does not influence price competition[15].

Recall that $\delta = \tilde{q} - \underline{q}$.

Firm NL's demand is given by:

$$\underline{D} = \begin{cases} \overline{\theta} - \underline{\theta} & \text{if} \quad \underline{p} \leq \tilde{p} - \overline{\theta}\delta \\ \frac{\tilde{p}-\underline{p}}{\delta} - \underline{\theta} & \text{if} \quad \tilde{p} - \overline{\theta}\delta < \underline{p} < \tilde{p} - \underline{\theta}\delta \\ 0 & \text{if} \quad \underline{p} \geq \tilde{p} - \underline{\theta}\delta \end{cases}$$

Its profit is then given by:

$$\underline{\pi} = \begin{cases} (\overline{\theta} - \underline{\theta})(\underline{p} - c(\underline{q})) & \text{if} \quad \underline{p} \leq \tilde{p} - \overline{\theta}\delta \\ (\frac{\tilde{p}-\underline{p}}{\delta} - \underline{\theta})(\underline{p} - c(\underline{q})) & \text{if} \quad \tilde{p} - \overline{\theta}\delta < \underline{p} < \tilde{p} - \underline{\theta}\delta \\ 0 & \text{if} \quad \underline{p} \geq \tilde{p} - \underline{\theta}\delta \end{cases}$$

First order conditions yield:

$$\underline{p} = \frac{\tilde{p} - \underline{\theta}\delta + c(\underline{q})}{2} \tag{8}$$

(8) corresponds to the best reply of the non-labelled firm if the provided value of $\underline{p}$ is between $\tilde{p} - \overline{\theta}\delta$ and $\tilde{p} - \underline{\theta}\delta$.

Consequently, the best reply correspondence of Firm NL is given by:

$$\underline{\varphi}(\tilde{p}) = \begin{cases} [c(\underline{q}), y] & \text{if} \quad \tilde{p} \leq c(\underline{q}) + \underline{\theta}\delta \\ \frac{\tilde{p}-\overline{\theta}\delta+c(\underline{q})}{2} & \text{if} \quad c(\underline{q}) + \underline{\theta}\delta < \tilde{p} < (2\overline{\theta} - \underline{\theta})\delta + c(\underline{q}) \\ \tilde{p} - \overline{\theta}\delta & \text{if} \quad \tilde{p} \geq (2\overline{\theta} - \underline{\theta})\delta + c(\underline{q}) \end{cases} \tag{9}$$

Calculations are analogous to provide the best reply for Firm L:

$$\tilde{\varphi}(\underline{p}) = \begin{cases} [c(\tilde{q}), y] & \text{if} \quad \underline{p} \leq c(\tilde{q}) - \overline{\theta}\delta \\ \frac{\underline{p}+c(\tilde{q})+\overline{\theta}\delta}{2} & \text{if} \quad c(\tilde{q}) - \overline{\theta}\delta < \underline{p} < c(\tilde{q}) + (\overline{\theta} - 2\underline{\theta})\delta \\ \underline{p} + \underline{\theta}\delta & \text{if} \quad \underline{p} \geq c(\tilde{q}) + (\overline{\theta} - 2\underline{\theta})\delta \end{cases} \tag{10}$$

[15] In fact, it is taken into account in the step of quality choice.

Proof of Result 1 and Corollary 1. Suppose an eco-label is set up with $\tilde{q}$ satisfying Inequality (1).

We first determine the price equilibrium between a labelled and a non-labelled firm.

In such conditions the best reply of Firm NL is simply given by:

$$\underline{\varphi}(\tilde{p}) = \tilde{p} - \overline{\theta}\delta_q \quad \forall \tilde{p} \in [c(\tilde{q}), y],$$

conditions specified in the two first lines of (9) giving the best reply of Firm NL, being impossible. The best reply of Firm L is still given by (10). The only intersection between both best replies is given by the couple of prices:

$$\begin{cases} \underline{p} = c(\tilde{q}) - \overline{\theta}\delta_q \\ \tilde{p} = c(\tilde{q}). \end{cases}$$

We now determine the quality equilibrium. The quality game may be described as follows:

$1\backslash 2$	$\underline{q}$	$\tilde{q}$
$\underline{q}$	$(0,\, 0)$	$(\underline{\pi} > 0, \tilde{\pi} = -I)$
$\tilde{q}$	$(\tilde{\pi} = -I, \underline{\pi} > 0)$	$(-I, -I)$

where $\tilde{\pi}$ and $\underline{\pi}$ are respectively the profits of a labelled firm and a non-labelled one at price equilibrium.

At equilibrium both firms produce $\underline{q}$.

Whether an eco-label is set up or not, the situation remains the same for both firms, which implies the indifference of firms towards the label.

After setting up an eco-label, no firm gets the label thus no environmental improvement is expected. This ends the proof of the result.

By the theorem of mean value Inequality (1) holds for all possible values of labelling criteria. Hence Result 1 applies for all $\tilde{q} \in [\underline{q}, \overline{q}]$, which proves the corollary.

■

Proof of Result 2. In such conditions, the best reply of Firm L is given simply by:

$$\tilde{\varphi}(\underline{p}) = \underline{p} + \underline{\theta}\delta_q \quad \forall \underline{p} \in [c(\underline{q}), y],$$

conditions specified in the two first lines of (10) giving the best reply of Firm L, being impossible. The best reply of Firm NL is still given by (9). The only intersection between both best replies in the space $(\underline{p}, \tilde{p})$, is given by the couple of prices:

$$\begin{cases} \underline{p} = c(\underline{q}) \\ \tilde{p} = c(\underline{q}) + \underline{\theta}\delta_q. \end{cases}$$

At these prices Firm NL is not active, i.e. has no demand.

The quality game may be described as follows.

$1\backslash 2$	$\underline{q}$	$\tilde{q}$
$\underline{q}$	$(0, 0)$	$(\underline{\pi} = 0, \tilde{\pi})$
$\tilde{q}$	$(\tilde{\pi}, \underline{\pi} = 0)$	$(-I, -I)$

where $\tilde{\pi}$ and $\underline{\pi}$ are the profits respectively of Firms L and NL at the equilibrium prices (given by (3)).

1. if $\tilde{\pi} > 0$, at the unique quality equilibrium, Firm 1 chooses $\tilde{q}$ and Firm 2 chooses $\underline{q}$. Position of firms towards the eco-label requires the specification of the preference of firms towards activity.

   Under $\mathcal{PA}$, since Firm 2 is active when there is no eco-label, it resists to the eco-label while Firm 1 supports it.

   When $\tilde{\pi} = 0$, the simultaneous game admits three equilibria $(\underline{q}, \underline{q})$, $(\underline{q}, \tilde{q})$ and $(\tilde{q}, \underline{q})$. Firm 1 choosing first and the three situations amounting to the same in terms of profit, we must consider its activity in each one. When it chooses $\tilde{q}$, (Firm 2 chooses $\underline{q}$), it has all the demand. Under $\mathcal{PA}$, the equilibrium involves Firm 1 producing $\tilde{q}$ and serving all the demand and Firm 2 proposing without selling $\underline{q}$.

2. If $\tilde{\pi} < 0$, at the unique quality equilibrium, both firms choose $\underline{q}$, thus making no profit. Hence at quality equilibrium both firms are active producing $\underline{q}$ and making no profit. Whether an eco-label is set up or not, the situation is the same for each firm. Both firms are thus indifferent towards the eco-label.

■

Proof of Corollary 2.

When $\mathcal{H}2$ holds, by the theorem of mean value, there exists $\hat{q} \in [\underline{q}, \tilde{q}]$ such that $c(\tilde{q}) - c(\underline{q}) = c'(\hat{q})(\tilde{q} - \underline{q})$. Hence Result 2 applies for all $\tilde{q} \in [\underline{q}, \overline{q}]$. The quality equilibrium corresponds to Firm 1 producing $\tilde{q}$ and Firm 2 producing $\underline{q}$, only if the profit of Firm L at price equilibrium is positive. This profit is given by:

$$\tilde{\pi} = (c(\underline{q}) - c(\tilde{q}) + \underline{\theta}(\tilde{q} - \underline{q}))(\bar{\theta} - \underline{\theta}) - I(\tilde{q} - \underline{q})$$

If c and I are convex functions, $\tilde{\pi}$ is a concave function w.r.t. $\tilde{q}$.

1) As $\tilde{\pi}(\underline{q}) = 0$, a necessary and sufficient condition for $\tilde{\pi}$ to be positive for all $\tilde{q}$ is $\tilde{\pi}(\overline{q}) > 0$, which is equivalent to $[c(\underline{q}) - c(\overline{q}) + \underline{\theta}(\overline{q} - \underline{q})](\overline{\theta} - \underline{\theta}) - I(\overline{q} - \underline{q}) > 0$.

2) A necessary and sufficient condition for $\tilde{\pi}$ to be negative for all $\tilde{q}$ is $\tilde{\pi}'(\underline{q}) \leq 0$, which is equivalent to $(\underline{\theta} - c'(\underline{q}))(\bar{\theta} - \underline{\theta}) - I'(0) \leq 0$

■

Proof of Result 3.

First the equilibium in prices between a labelled and a non-labelled firm is determined.

If firms are both active at price equilibrium, prices are given by:

$$\begin{cases} \tilde{p} = \frac{\underline{p} + c(\tilde{q}) + \overline{\theta}\delta_q}{2} \\ \underline{p} = \frac{\tilde{p} - \underline{\theta}\delta_q + c(\underline{q})}{2}, \end{cases} \tag{11}$$

which after calculations yield

$$\begin{cases} \underline{p} = (1/3)[2c(\underline{q}) + c(\tilde{q}) + (\overline{\theta} - 2\underline{\theta})(\tilde{q} - \underline{q})] \\ \tilde{p} = (1/3)[c(\underline{q}) + 2c(\tilde{q}) + (2\overline{\theta} - \underline{\theta})(\tilde{q} - \underline{q})]. \end{cases}$$

For the preceding couple of prices to be the equilibrium, it is necessary and sufficient that it satisfy:

$$\underline{p} > c(\underline{q}),\ \tilde{p} > c(\tilde{q}), \tag{12}$$

$$\underline{\theta} < \frac{\tilde{p} - \underline{p}}{\tilde{q} - \underline{q}} < \overline{\theta}. \tag{13}$$

Noting a redundancy between Inequalities (12) and (13), they in fact amount to Inequalities (4).

Note first that when Inequalities (4) are satisfied, In the price competition between a labelled and a non-labelled firm, the non-labelled firm necessarily makes a positive profit at equilibrium. The quality equilibrium depends on the profit of a labelled firm, which depends on the investment made to adopt the label.

1) If (5) is satisfied, the profit of the labelled firm is also positive at the equilibrium prices. The quality game once an eco-label is set up may be described as follows:

$1\backslash 2$	$\underline{q}$	$\tilde{q}$
$\underline{q}$	$(0, 0)$	$(\underline{\pi} > 0, \tilde{\pi} \geq 0)$
$\tilde{q}$	$(\tilde{\pi} \geq 0, \underline{\pi} > 0)$	$(-I, -I)$

where $I = I(\delta)$, $\tilde{\pi}$ and $\underline{\pi}$ are the profits respectively of Firms L and NL at price equilibrium. Consequently, the simultaneous game admits two equilibria $(\underline{q}, \tilde{q})$ and $(\tilde{q}, \underline{q})$. Firm 1 playing first, it chooses the situation that ensures to it the best profit. Both firms make positive profits if an eco-label is set up. Hence they are better off with an eco-label and support it.

2) (7) implies that the profit of the labelled firm at price equilibrium (in the competition between a labelled and a non-labelled firm) is negative. Hence the quality game admits a unique equilibrium: $(\underline{q}, \underline{q})$, in which case both firms make no profit.

The situation is the same without eco-label. Firms are thus indifferent towards the eco-label. ∎

Appendix B

Proofs of Result 4 and Corollary 3

Setting up a label with $\tilde{q} = \underline{q}$ (or setting up no eco-label) results in a total surplus equal to (firms' profits being equal to zero):

$$S^T(\tilde{q} = \underline{q}) = \int_{\underline{\theta}}^{\overline{\theta}} (\theta \underline{q} - c(\underline{q}))d\theta - D(\underline{q})(\overline{\theta} - \underline{\theta}).$$

When an eco-label is set up such that $\delta \in]0, \overline{\delta}]$, one firm will leave the market resulting in a resistance cost C_R. The total surplus is then given by:

$$S^T(\tilde{q} > \underline{q}) = \tilde{\pi} + \int_{\underline{\theta}}^{\overline{\theta}} (\theta \tilde{q} - \tilde{p})d\theta - D(\tilde{q})(\overline{\theta} - \underline{\theta}) - C_R$$

Note that

$$\lim_{\tilde{q} \to \underline{q}^+} S^T = S^T(\tilde{q} = \underline{q}) - C_R$$

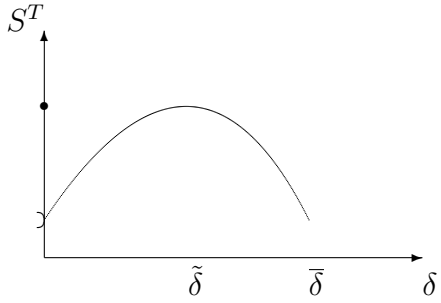
The resistance cost is indeed here the only source of discontinuity.

First order condition yields:

$$\tilde{\delta} = \frac{(\overline{\theta} - \underline{\theta})(\underline{\theta} + \overline{\theta} - 2\alpha + 2\mu)}{4\beta}$$

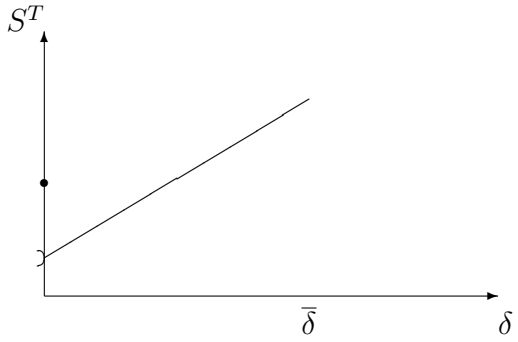
First note that for the considered values of α, we always have $\tilde{\delta} \geq 0$. But we do not always have $\tilde{\delta} < \overline{\delta}$.

When $\tilde{\delta} < \overline{\delta}$, the surplus function may be represented as follows:



On $]0, \overline{\delta}]$, the function is maximal at $\tilde{\delta}$. The optimal value of δ depends on the comparison between $S^T(0)$ and $S^T(\tilde{\delta})$.

When $\tilde{\delta} > \overline{\delta}$, the surplus function may be represented as follows:



The optimal value of the surplus function on $[0, \overline{\delta}]$ depends in this case on the comparison between $S^T(0)$ and $S^T(\overline{\delta})$.

$\tilde{\delta} > \overline{\delta}$ only if $\alpha > \frac{3\underline{\theta} - \overline{\theta} - 2\mu}{2}$, which is possible only when $\frac{3\underline{\theta} - \overline{\theta} - 2\mu}{2} < 2\underline{\theta} - \overline{\theta}$, equivalent to $\mu > \frac{\overline{\theta} - \underline{\theta}}{2}$.

To describe the total surplus function on the interval $]0, \overline{\delta}]$, two cases have to be distinguished:

Denote by

$$\alpha^* = \frac{3\underline{\theta} - \overline{\theta} - 2\mu}{2}$$

1. When $\mu > \frac{\overline{\theta} - \underline{\theta}}{2}$, two subcases are possible:

   - If $\alpha \geq \alpha^*$, we have $\tilde{\delta} \geq \overline{\delta}$, which implies that S^T is increasing on $]0, \overline{\delta}]$.
   - If $\alpha < \alpha^*$, we have $0 < \tilde{\delta} < \overline{\delta}$, hence S^T is increasing until $\tilde{\delta}$ then decreasing.

2. When $\mu \leq \frac{\overline{\theta} - \underline{\theta}}{2}$, we have $\alpha^* \geq 2\underline{\theta} - \overline{\theta}$. We always have $0 < \tilde{\delta} < \overline{\delta}$ thus S^T is increasing until $\tilde{\delta}$ then decreasing.

Because of the discontinuity of the surplus at $\delta = 0$, to determine the optimal value of δ, we have to compare the maximal value of S^T reached on the interval $]0, \overline{\delta}]$ with its value at $\delta = 0$.

We have for all $\delta \in]0, \overline{\delta}]$,

$$S^T(\delta) - S^T(\delta = 0) = (\underline{\theta} - \alpha)(\overline{\theta} - \underline{\theta})\delta - \beta\delta^2 + \frac{(\overline{\theta} - \underline{\theta})^2}{2}\delta + \mu\delta(\overline{\theta} - \underline{\theta}) - C_R$$

Recall

$$f(\delta) = (\underline{\theta} - \alpha)(\overline{\theta} - \underline{\theta})\delta - \beta\delta^2 + \frac{(\overline{\theta} - \underline{\theta})^2}{2}\delta + \mu\delta(\overline{\theta} - \underline{\theta})$$

and note that $f(\delta) > 0$ on $]0, \overline{\delta}]$.

The proof of the corollary follows immediately. ∎

Proof of Result 5

The price equilibrium for a labelled and a non-labelled firm is given by:

$$\begin{cases} \underline{p} = \frac{1}{3}[2\alpha\underline{q} + \alpha\tilde{q} + (\overline{\theta} - 2\underline{\theta})(\tilde{q} - \underline{q})] \\ \tilde{p} = \frac{1}{3}[\alpha\underline{q} + 2\alpha\tilde{q} + (2\overline{\theta} - \underline{\theta})(\tilde{q} - \underline{q})]. \end{cases} \tag{14}$$

Profits at equilibrium are given by:

$$\begin{cases} \underline{\pi} = \frac{1}{9}(\tilde{q} - \underline{q})(\overline{\theta} - 2\underline{\theta} + \alpha)^2 \\ \tilde{\pi} = \frac{1}{9}(\tilde{q} - \underline{q})(2\overline{\theta} - \underline{\theta} - \alpha)^2 - \beta(\tilde{q} - \underline{q})^2 \end{cases} \tag{15}$$

Note first that $\underline{\pi} > 0$.

If $\tilde{\pi} < 0$, at the only Nash equilibrium of the game, both firms produce quality $\underline{q}$. This amounts exactly to the same as the situation without eco-label (for consumers, firms and the environment).

If $\tilde{\pi} \geq 0$, at the only perfect equilibrium, two active firms produce respectively $\underline{q}$ and $\tilde{q}$.

$\tilde{\pi} \geq 0$ is equivalent to

$$\tilde{q} - \underline{q} \leq \frac{(2\overline{\theta} - \underline{\theta} - \alpha)^2}{9\beta}.$$

As in the preceding case, note that $\tilde{q}$ corresponding to $\delta = 0$ (i.e. $\tilde{q} = \underline{q}$) is strictly equivalent to the situation without eco-label and that labelling criteria corresponding to $\tilde{\pi} < 0$, i.e. $\delta > \frac{(2\overline{\theta} - \underline{\theta} - \alpha)^2}{9\beta}$, (Case described in Result **??**) do modify nothing in terms of competition and environment relative to the situation without eco-label, thus amount to set up no eco-label.

Hence to examine all the relevant cases, it is sufficient to deal with labelling criteria satisfying

$$\delta(=\tilde{q}-\underline{q}) \in [0, \overline{\delta} = \frac{(2\overline{\theta}-\underline{\theta}-\alpha)^2}{9\beta}].$$

The authority maximizes the total surplus

$$S^T = \tilde{\pi} + \underline{\pi} + S_c - D(\underline{q})(\hat{\theta}-\underline{\theta}) - D(\tilde{q})(\overline{\theta}-\hat{\theta})$$

on $[0, \overline{\delta}]$.

Note that the total surplus is a concave function. First order condition yields

$$\tilde{\delta} = \frac{(2\overline{\theta}-\underline{\theta}-\alpha)(4\overline{\theta}+\underline{\theta}-5\alpha+6\mu)}{36\beta}$$

To calculate the optimal value of δ, we must compare $\tilde{\delta}$ with the bounds of the considered interval. Indeed three cases are a priori possible:

When $\tilde{\delta} < 0$, the total surplus reaches its maximum at $\delta = 0$. It is optimal to set up no eco-label.

When $0 < \tilde{\delta} < \overline{\delta}$, the total surplus reaches its maximal value at $\tilde{\delta}$.

Finally when $\tilde{\delta} > \overline{\delta}$, the surplus reaches its maximum at $\delta = \overline{\delta}$.

$\tilde{\delta} \geq 0$ is equivalent to $\alpha \leq \overline{\alpha} = \frac{4\overline{\theta}+\underline{\theta}+6\mu}{5}$. $\overline{\alpha}$ must thus be compared with the bounds of the considered interval: $2\underline{\theta}-\overline{\theta}$ and $2\overline{\theta}-\underline{\theta}$.

We always have $\overline{\alpha} > 2\underline{\theta}-\overline{\theta}$ but $\overline{\alpha} < 2\overline{\theta}-\underline{\theta}$ only if $\mu < \overline{\theta}-\underline{\theta}$.

Now $\tilde{\delta} < \overline{\delta}$ is equivalent to $\alpha > \underline{\alpha} = 5\underline{\theta} - 4\overline{\theta} + 6\mu$.

When $\mu > \overline{\theta}-\underline{\theta}$, $\tilde{\delta} > \overline{\delta}$.

When $\mu < \overline{\theta}-\underline{\theta}$, $\underline{\alpha} < \overline{\alpha}$. But $\underline{\alpha} > 2\underline{\theta}-\overline{\theta}$ only if $\mu > \frac{\overline{\theta}-\underline{\theta}}{2}$.

■